Distribution, Abundance and Population Structuring of Beaked Whales in the Great Bahama Canyon, Northern Bahamas

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LONG-TERM GOALS

Atypical mass strandings of beaked whales have been correlated with naval sonar exercises (e.g. Simmonds and Lopez-Juraco 1991; Frantzis 1998; Evans and England 2001) highlighting a need for a better understanding of beaked whale population ecology. The long-term goal of this project is to fill key data gaps on the distribution, abundance, habitat use and population structuring of beaked whales in the Great Bahama Canyon. The study area includes the US Navy's Andros-AUTEC Operating Areas where fleet readiness training involves regular use of mid-frequency active sonars.

OBJECTIVES

The primary objectives of the study are:

1) To use visual survey techniques to document beaked whale distribution and habitat use, and to estimate abundance in the Great Bahama Canyon.

2) To use photo-identification techniques to extend an existing photographic catalogue of individual beaked whales, which will be queried to examine the distribution and movements of identified individuals, and to assess abundance using mark-recapture techniques.

3) To use remote biopsy techniques to collect skin and blubber samples to contribute to the study of beaked whale diet (through fatty acid, stable isotope and contaminant analyses) and stock structure (using molecular genetic approaches).

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APPROACH

Using standardized line-transect methods, three ship-based visual and acoustic surveys were completed during FY07-08 to assess patterns of distribution and relative abundance in the Great Bahama Canyon. Transect lines were randomly placed within four rectangular strata (NE Providence Channel, NW Providence Channel, Tongue of the Ocean and the Cul de Sac, Figure 1). Upon sightings, the ship broke transect to confirm species identification, estimate group size and to collect photo-ID and biopsy samples. An additional fourth survey in FY09 returned to areas of highest concentration of beaked whales to increase the number of biopsy samples and to deploy satellite dart-tags. Additionally, small vessel surveys have been conducted during FY10 to collect biopsy samples and photo-identification data outside the canyon, in Exuma Sound and the Great Abaco Canyon, to evaluate population structuring and movement patterns of beaked whales in the region.

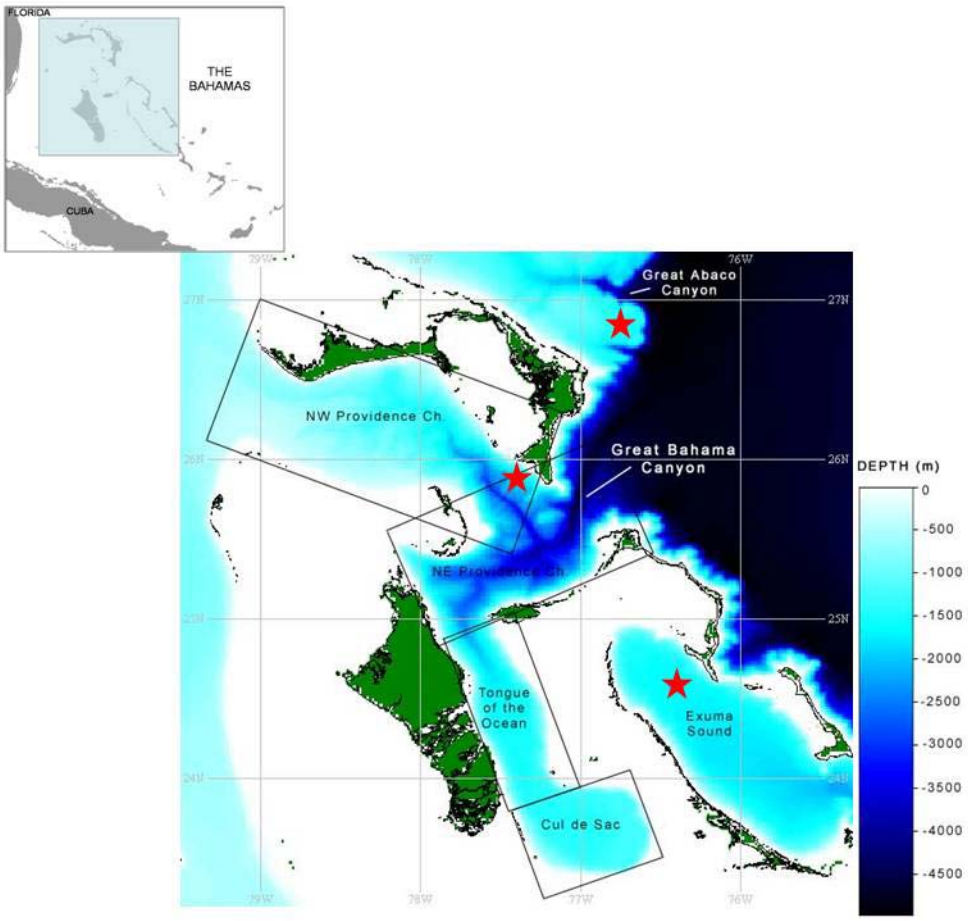

Figure 1. The Great Bahama Canyon branches into Northwest Providence Channel and from Northeast Providence Channel south into Tongue of the Ocean and the Cul de Sac, and reaches depths of more than 4000m. The three areas where field effort occurred during FY10 are shown by the red stars. These include: Exuma Sound, Great Abaco Canyon and off the SW coast of Great Abaco Island. The rectangular survey grids where large vessel surveys have been conducted are also shown.

WORK COMPLETED

Data Collection

During FY10 vessel-based surveys were completed in Exuma Sound (Figure 2), and in the Little and Great Abaco Canyons on the Atlantic side (east side) of Abaco Island (Figure 3). Combined these surveys covered 4113 km of visual search effort using 2 different platforms: a 15.7m catamaran and 6.8m rigid-hulled inflatable. There were 64 sightings of beaked whales, comprising 3 species: Blainville's beaked whale (*Mesoplodon densirostris*), n=15, Gervais' beaked whale (*M. europaeus*), n=14 and Cuvier's beaked whale (*Ziphius cavirostris*), n=20. It is noteworthy that Gervais' beaked whale was the most common beaked whale species sighted in Exuma Sound. There were 42 biopsy samples collected from beaked whales during this field effort. Due to weather and the more evasive behavior of whales, it was not possible to collect tissue samples from beaked whales in Exuma Sound. The opposite was true for the East Abaco survey which is where all the biopsy samples were collected during FY10.

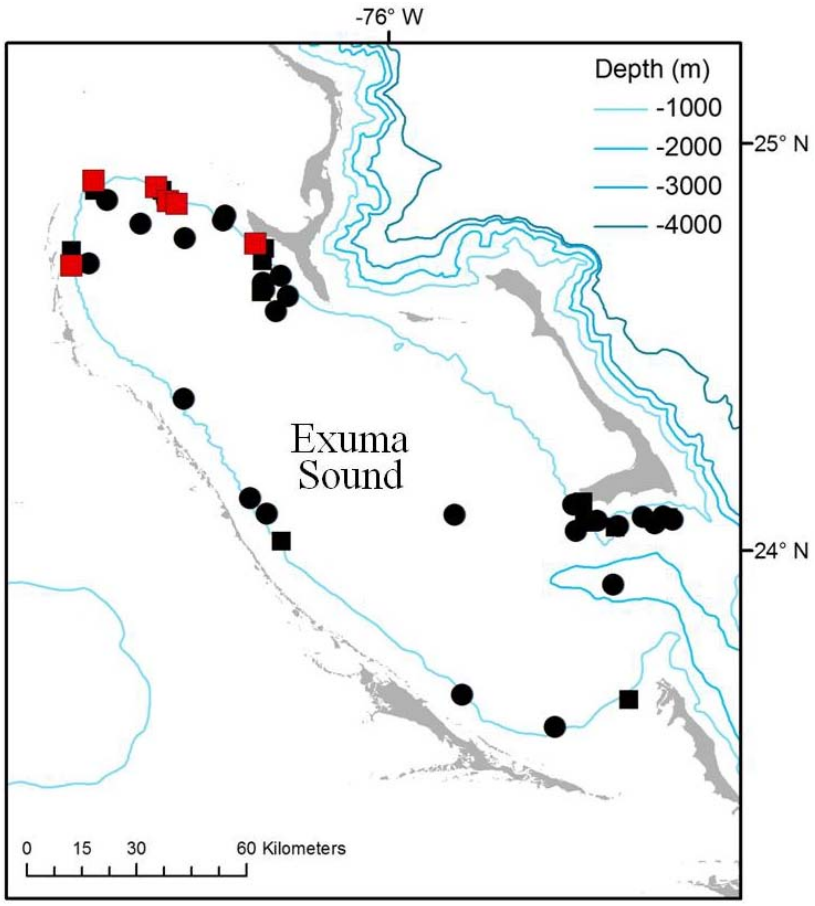

Figure 2. Cetacean sightings in Exuma Sound during FY10. Beaked whale groups are denoted by black circles and all other cetacean species by black squares. Sightings during which biopsy samples were taken are shown in red. Although 28 beaked whale groups were found, no biopsy samples were successfully collected.

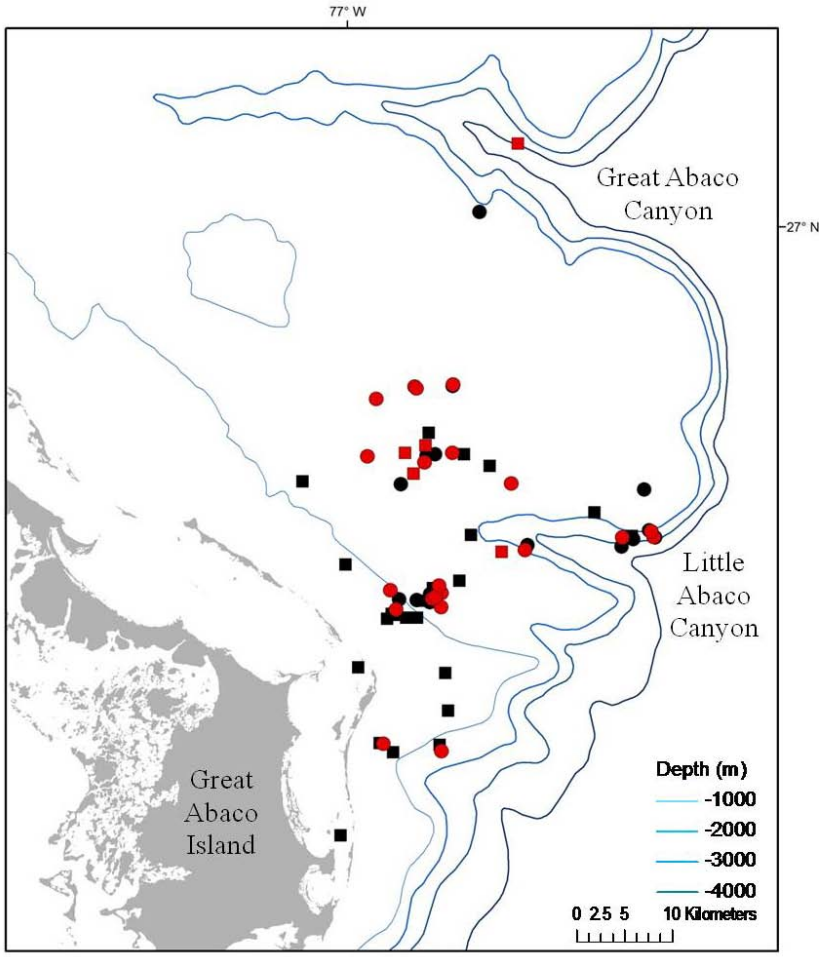

Figure 3. Cetacean sightings off the east side of Great Abaco Island in the northern Bahamas during FY10. Beaked whale groups are denoted by black circles and all other cetacean species by black squares. Sightings during which biopsy samples were taken are shown in red. Forty-two beaked whale biopsy samples were collected.

Photographic Mark-Recapture

Using methodologies developed by Durban and Elston (2005), mark-recapture models were fit to photo-identification data to estimate abundance and turnover of Blainville's beaked whales on the Weapons Range at AUTEC. Photographs were graded for quality and individuals were rated on presence or absence of distinctive notches in the dorsal fin and graded for distinctiveness. Thirty-eight distinctively-marked whales were identified from high-quality photographs, with 12 whales seen in multiple years (median = 1, maximum = 4 years). Identification histories were compiled for each individual whale, consisting of a record of 1's and 0's to indicate if it was identified (1) or not (0) over a series of annual sampling intervals between 2005-2008. Open- and closed-population mark-recapture generalized linear models were used to estimate abundance and infer turnover at different temporal scales using WinBUGS (Lunn et al. 2000). Estimates were rescaled to account for whales that were not sufficiently distinct for between-year matches (e.g. Durban et al. 2010).

Chemical Analyses

Chemical analyses of skin and blubber biopsies have been carried out by Gina Ylitalo, Dr. David Herman and colleagues at the Northwest Fisheries Science Center, NOAA Fisheries. Nitrogen and carbon stable isotope ratios (SI) in skin and blubber fatty acids (FA) were analyzed in biopsy samples from 48 beaked whales (Blainville's, n=28; Cuvier's, n=19; Gervais', n=1) collected from the Great Bahama Canyon during FY07-09 (Figure 4). Results of SI and FA work (reported previously to ONR) showed that there were differences in prey preferences and that these whales showed site fidelity to localized foraging areas. The Blainville's and Cuvier's samples were also analyzed for Persistent Organic Pollutants (POPs) in order to further elucidate foraging habits and population structure. The analytical methods used to analyze these samples for FAs, SIs, and POPs are described in Herman *et al.* (2005) and Sloan *et al.* (2005).

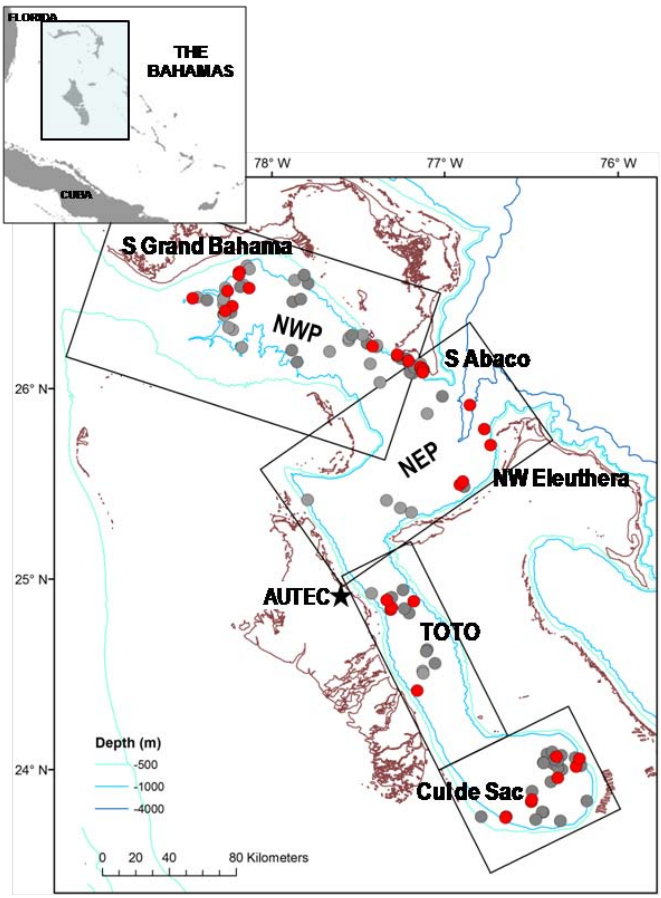

Figure 4. Beaked whale sightings in the Great Bahama Canyon during which biopsy samples were taken (red circles) and were not taken (grey circles). Samples were collected from five different geographical areas: S Grand Bahama, S Abaco, NW Eleuthera, Tongue of the Ocean (TOTO) and the Cul de Sac. Samples from Blainville's and Cuvier's beaked whales were analyzed during FY10 for POPs.

RESULTS

Photographic Mark-Recapture

The closed population model estimated a high probability of annual variation in catchability ($p = 0.84$) but provided little support for individual heterogeneity ($p = 0.05$). A Bayesian approach was used to analyze and convey uncertainty, resulting in a most probable abundance estimate of 64 whales using the Weapons Range over the 4-year period (75% highest probability interval [HPI] = 58-71). An open population model with varying annual catchabilities estimated a similar overall population size of 69 whales (75% HPI = 56-97) but also allowed estimation of an average annual abundance of 49 whales (75% HPI = 45-56). These estimates are notably higher than the instantaneous abundance estimated using passive acoustic monitoring on the Weapons Range (~25 whales) (Moretti *et al.* 2006, Marques e*t al.* 2009). In combination, these estimates show increased abundance with longer temporal durations. These differences imply turnover of individual whales on the range, and highlight the value of individual-based monitoring through photo-identification.

It is worth noting that 12 of 36 whales (33%) were seen in more than one year suggesting that some whales exhibit site fidelity to the AUTEC range. Similarly, two whales photographed off East Abaco in June 2010 had been seen previously in the same area in 1998, suggesting long-term site fidelity.

Chemical Analyses

Reported by David P Herman, Douglas G. Burrows, Gladys K.Yanagida, Richard H. Boyer and Gina M. Ylitalo (NWFSC, NOAA Fisheries).

The POP patterns (and ratios) differed between the five sampling regions for Blainville's beaked whales (Figure 5). The PC3 axis did not show any significant resolution between the regions and is therefore not shown. In contrast, the PC4 axis resolves the Cul de Sac, TOTO, and NW Eleuthera groups, suggesting that these whales exhibit long-term foraging site fidelity. However, sample sizes are quite small.

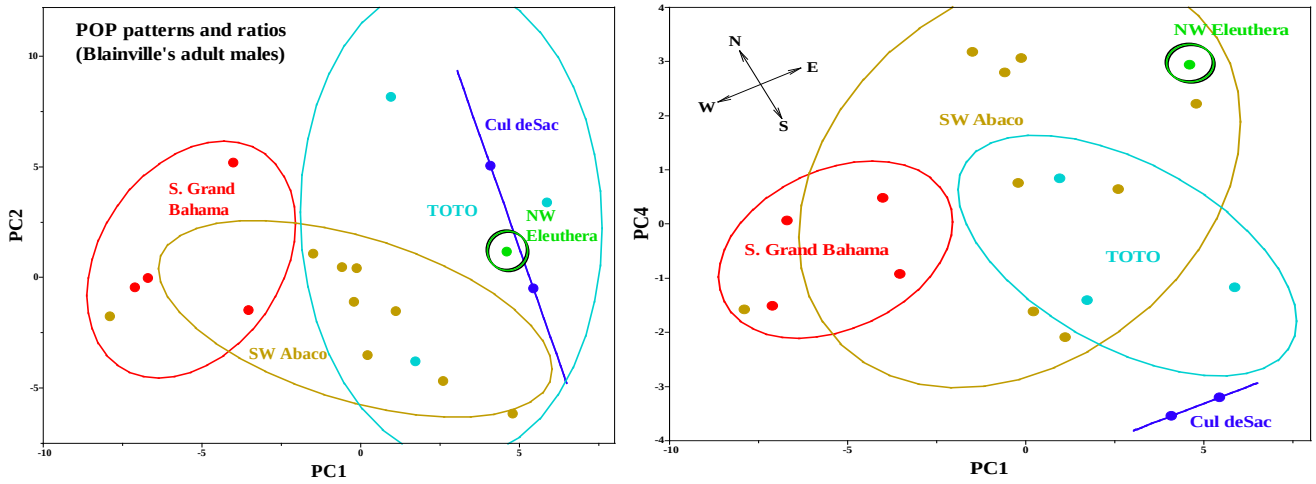

Figure 5. Principal Component Analysis plots depicting the differences in POP profiles (and ratios) among five sampling/foraging locations for adult male Blainville's beaked whales. Ovals represent the 80% probability density intervals at each location, suggesting that these whales exhibit long-term foraging site fidelity.

Similar analyses were run for adult male Cuvier's beaked whales (Figure 6). Despite sample size constraints, there are some indications that the POP patterns for the Cul de Sac, NW Eleuthera, and S. Grand Bahama are substantially different from one another.

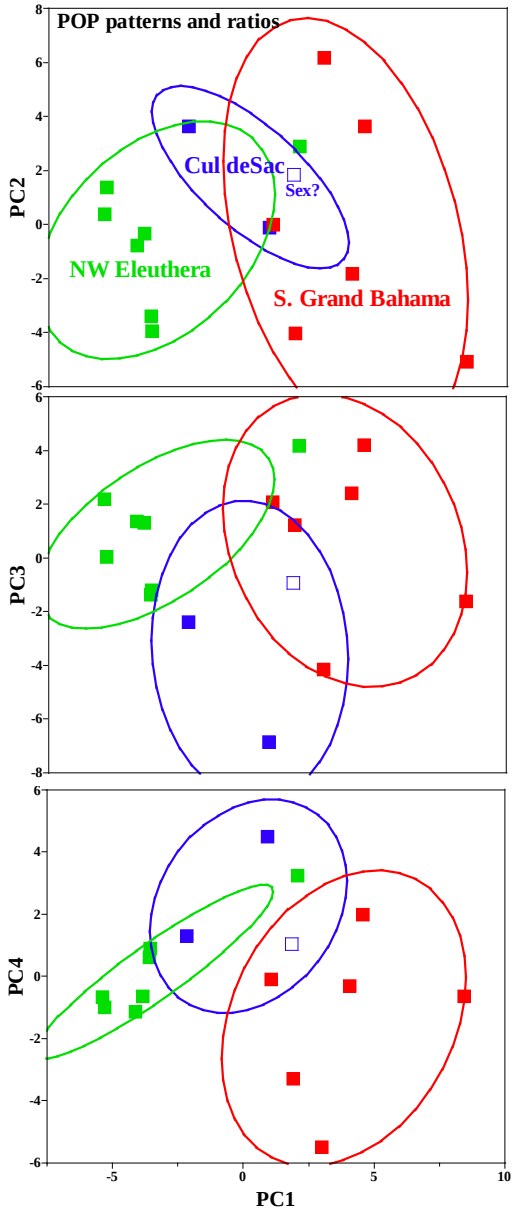

Figure 6. Principal Component Analysis plots (PC1 vs PC2, PC3 and PC4) depicting the differences in POP profiles (and ratios) among three sampling/foraging locations for Bahamas adult male Cuvier's beaked whales. The locations shown are: Cul de Sac (blue), S. Grand Bahama (red), NW Eleuthera (green).

Findings reported here are analogous to what was reported previously for Blainville's and Cuvier's beaked whale dietary FAMEs results (see FY09 report) in which it was concluded that these whales seem to exhibit a relatively high degree of short-term foraging site fidelity. The POP results appear to

indicate that these whales exhibit long-term foraging site fidelity as well, although sample sizes are quite small.

Analysis of absolute lipid-normalized concentrations of POPs suggests only slight inter-species differences. The levels of contamination in the Bahamas whales were not inordinately high and for the most part comparable to levels found in Baird's beaked whales (*Berardius bairdii*) from the central Aleutian Islands (Table 1) and in resident killer whales (*Orcinus orca*) in the Gulf of Alaska.

Table 1. Comparison of contaminant concentration levels (ng/g lipid) between Blainville's and Cuvier's beaked whales sampled in the Great Bahama Canyon. These levels were similar to those recorded for Baird's Beaked whale sampled in the Central Aleutian Islands, Alaska. Results do not include reproductive females.

Contaminant	**Blainsville's** (n=15)	**Cuviers'** (n=11)	**Baird's Beaked[a] (CAI)** (n=7)
	Mean Stdev	Mean Stdev	Mean Stdev
ΣPCB's	14100 ± 8600	15800 ± 6400	12000 ± 4600
ΣDDT's	16800 ± 12200	22000 ± 10000	15000 ± 7500
ΣCHLR's	2020 ± 1300	2030 ± 800	1600 ± 700
ΣHCH"s	12 ± 14	4.0 ± 6.7	64 ± 34
ΣPBDE's	500 ± 400	300 ± 120	5 ± 8

a) Contaminant levels measured in Baird's Beaked Whales biopsy sampled in the Central Aleutian Islands (AK) during the spring/summer of 2003 (NWFSC unpublished results)

Since there was no significant difference in concentrations of POPs between the beaked whale species from the Bahamas (Table 1), POP results for these two species were pooled together and the mean concentrations computed at each of the five sampling locations (not including reproductive-age females). Differences were found between these geographic regions as shown in the summary POP concentration data in Table 2. Despite sample size constraints, the mean POP concentration levels at NW Eleuthera, TOTO, and in the Cul de Sac regions are similar and higher by a factor of two than levels from S. Grand Bahama and SW Abaco. The higher levels measured in these three locations suggests the existence of a POP "hot-spot" somewhere in Northeast Providence Channel and/or TOTO.

Table 2. Comparison of contaminant concentration levels (ng/g lipid) among the five sampling sites in the Great Bahama Canyon. Blainville's and Cuvier's beaked whales are pooled in this comparison. Results do not include reproductive females.

Contaminant	NW Eleuthera (n=3)		TOTO (n=3)		Cul deSac (n=4)		S.Grand Bahama (n=11)		SW Abaco (n=5)	
	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev
ΣPCB's	22000	± 5000	20000	± 13000	16000	± 7000	13000	± 7000	10000	± 6400
ΣDDT's	29000	± 6000	26000	± 20000	21000	± 11000	17000	± 11000	12000	± 10000
ΣCHLR's	2900	± 310	2900	± 1700	2300	± 1400	1800	± 900	1400	± 800
ΣHCH"s	15	± 10	23	± 21	13	± 13	2.9	± 7.6	4.6	± 6.7
ΣPBDE's	340	± 30	810	± 550	680	± 460	310	± 170	240	± 120

Genetic Analyses
Reported by Dr. Phil Morin, Southwest Fisheries Science Center (NOAA Fisheries).

Approximately 40 samples from Blainville's and Cuvier's beaked whales are being used to obtain DNA sequence from genetic regions to discover new single nucleotide polymorphisms (SNPs) for genetic analysis of the Bahamas (and other) populations. To date 24 regions have been sequenced in Cuvier's beaked whale, and 14 have been analyzed. Approximately 28 SNPs have been found in the first 14 regions analyzed, and a sufficient number of SNPs is expected in the remaining 17 regions. Another 7 regions are currently in progress, and after these are analyzed, the team will determine whether more regions are needed to obtain the target number of SNPs, or whether to begin analyses of Blainville's beaked whale.

All of the samples from the FY10 field season have been received and archived, and SNP genotyping will begin near the end of this calendar year, or early in 2011.

IMPACT/APPLICATIONS

This project is providing key information on the baseline population ecology of beaked whales in the Great Bahama Canyon to understand and mitigate the effects of naval activities within this area. Using multiple approaches (photo-identification and chemical analyses of biopsy samples to date), the initial findings suggest relatively fine-scale population structuring of beaked whales within the Great Bahama Canyon, in the form of relatively small subpopulations of whales that show local site fidelity. However on the AUTEC Weapons Ranges, although some animals photo-identified exhibit site fidelity, there appears to be movement of animals in and out of the area. Tyack *et al.* (submitted) report movements of beaked whales off range in response to multi-ship tactical sonar exercises at AUTEC. It is still unknown whether this movement is limited to the Tongue of the Ocean as none of the AUTEC whales have been resighted outside TOTO. When completed, the genetic analysis will provide further information on the extent and scale of population structuring of beaked whales in this area.

RELATED PROJECTS

Behavior Response Study (BRS)
This is a large, multi-national project in which responses of whales exposed to underwater sounds are measured to identify and mitigate their adverse effects. Phase I of the study took place during 2007 and 2008 in Tongue of the Ocean and was led by Dr. Ian Boyd (SMRU) as the Chief Scientist and holder of Bahamian research permit, and Dr. Brandon Southall (SEA, Ltd) was the Principal Investigator and holder of US permit. The project has been supported by the Office of Naval Research (ONR) and US Department of Defense (NAVSEA PEO IWS Mr. Joseph Johnson and OPNAV N45 Dr. Frank Stone). Diane Claridge was a co-Principal Investigator when BRS was conducted in the Bahamas. Photo-identification data and tissue samples collected during BRS is being contributed towards analysis of population structuring of beaked whales in the Great Bahama Canyon.

Monitoring beaked whale movements during the Submarine Commanders Course using satellite telemetry
This project is a collaborative project between the Bahamas Marine Mammal Research Organisation, Southwest Fisheries Science Center and the Naval Undersea Warfare Center (David Moretti). Satellite telemetry is being used to monitor the movements and diving behavior of beaked whales and other odontocete cetacean species on the US Navy's Atlantic Undersea Test and Evaluation Center (AUTEC) range before, during and after sonar exercises in which multiple ships are using their tactical sonars. Photo-identification and movement data are being contributed to the study of beaked whale population ecology in the area.

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